Low-Frequency Characteristics of Thin-Film Multijunction Thermal Voltage Converters

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***Abstract*— Low-frequency errors of thin-film multijunction thermal voltage converters are estimated using a simple model based on easily measured parameters. The model predictions are verified by measuring the converter's frequency characteristic using a digitally synthesized source.**

***Index Terms*— AC–DC power conversion, error analysis, frequency domain analysis, nonlinear systems, thermal converters, thin-film circuit thermal factors, thin-film circuits, transfer functions.**

I. Introduction

A method based on measurements of the dc transfer function and time constant has been developed to model thermal voltage converter (TVC) behavior in the low frequency range (0.001 Hz–100 Hz) [1]. Significant errors occur at low frequencies because the TVC output begins to track the square of the input. The higher the input voltage, the greater the heat loss through radiation and conduction along the input leads and the greater the deviation from the square-law response. Simulated ac–dc differences of a single junction TVC have been compared to ac–dc differences determined from measurements made using a digitally synthesized source [1]. TVC's with wire heaters have very long time constants, on the order of seconds, so the tracking errors are not significant at frequencies higher than about 10 Hz. Recently developed TVC's with thin-film heaters [2], [3] have time constants on the order of 20 ms and these devices were chosen to test the performance of the model because they have significant tracking errors up to 100 Hz. The results of simulated versus measured ac–dc differences made on different types of thin-film multijunction TVC's are reported in this paper.

A detailed study of the transient response of TVC's using vacuum thermoelements has been reported [4] which uses a perturbation method to solve the partial differential equation of heat flow in the heater to estimate low-frequency ac–dc differences. To perform the calculations, a complex set of measurements is required which includes the temperature coefficient of resistivity, thermal conductivity, specific heat, heat conduction, density of the heater material, and coefficient of emission from the lateral surface.

Manuscript received June 1, 1997; revised April 1, 1998.

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Publisher Item Identifier S 0018-9456(98)05467-9.

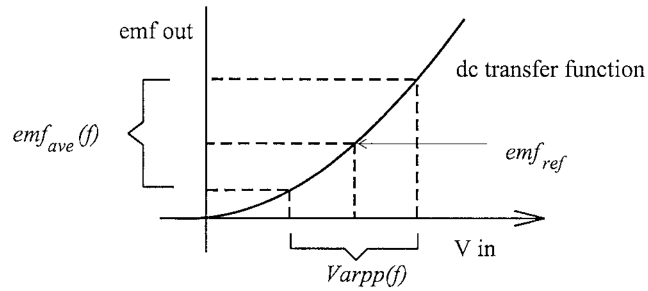

Fig. 1. Diagram showing how the average emf at frequency f is calculated using the peak-to-peak variation and the dc transfer function.

TABLE I
Test TVC Parameters

TVC	V_{in} (V)	emf_{out} (mV)	n	τ (ms)
A	2.5	85.8	1.94	34
B	1.5	67.1	1.91	18
C	1	83.3	1.95	42
D	1.5	36.1	1.99	18

The method proposed in [1] employs the TVC time constant, τ, and its steady-state transfer function. *The latter is determined by incrementing a dc input voltage in small steps between $\pm$ full scale and measuring the TVC output emf.* These two easily measured parameters are used in a simple TVC model to estimate low-frequency ac–dc differences.

II. Model

The simplest way to model the TVC behavior is to consider it to be the first order low pass filter. The frequency response of this filter is then used to scale the dc transfer function. The model performs the following functions.

1) Squares a simulated sinusoidal input voltage and filters it using a low pass filter with a cut off frequency $f_c = 1/(2\pi\tau)$, where τ is the TVC time constant.
2) Calculates the peak to peak variation, $Varpp(f)$, at the filter's output for a particular frequency with input voltage V applied.
3) Calculates the average output emf_{lf} at a very low frequency (where the tracking errors are maximum) with input voltage V applied.
4) Calculates the output emf_{ref} at a reference frequency (where tracking errors are negligible) with input voltage V applied.

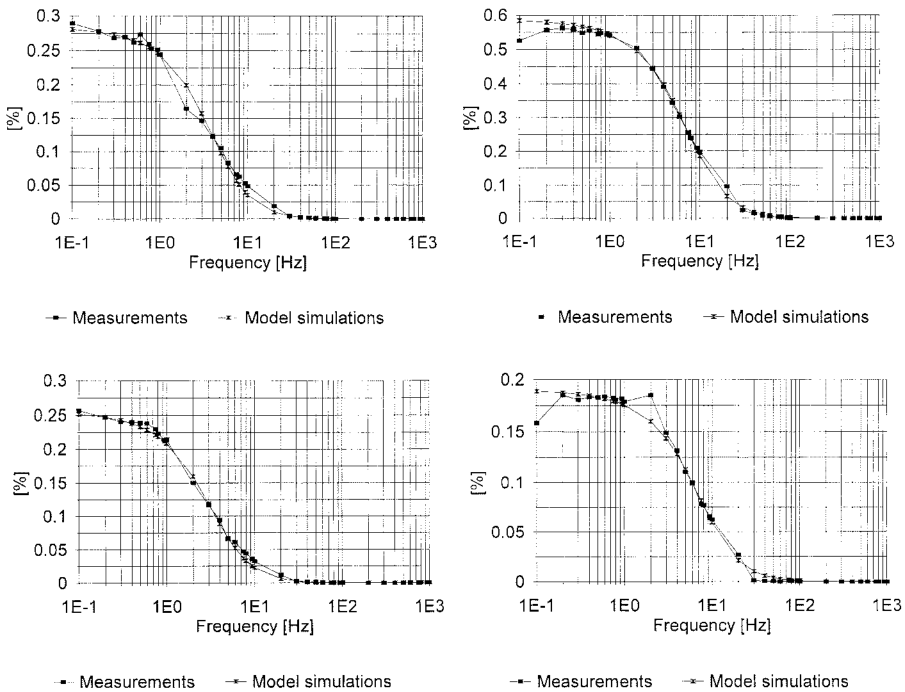

Fig. 2. Model simulations and measurements of ac–dc differences versus frequency for TVC's A, B, C, and D.

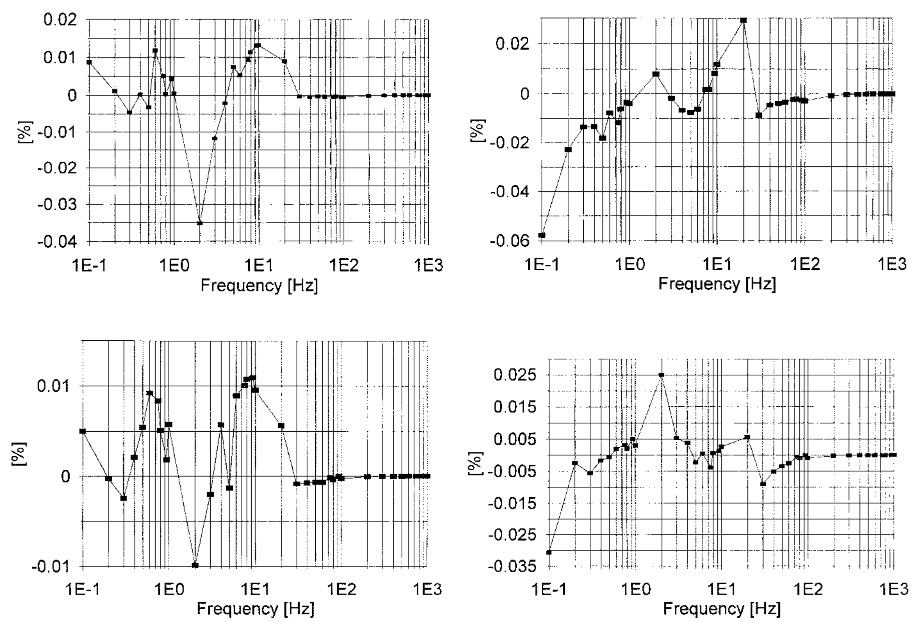

Fig. 3. Difference between model simulation and measurements of ac–dc differences versus frequency for TVC's A, B, C, and D.

At frequency F, the estimated ac–dc difference $\delta(f)$ is calculated using

$$\delta(f) = varpp(f)(emf_{ref} - emf_{lf})/emf_{ref}/n \tag{1}$$

where n is the power exponent that describes the transfer function of the TVC [1].

Four planar multijunction TVC's were measured for this analysis. Their nominal input voltages, V_{in}, output emf's emf_{out}, power exponents n, and time constants (τ) are given in Table I.

III. Measurements

The frequency characteristics of the four TVC's were measured between 0.1 Hz and 30 Hz using a digital multimeter to record the average TVC output emf with the input voltage supplied from a digitally synthesized source (DSS). The rms value of the output of this source is constant at all frequencies below 1 kHz to within five parts in 10^6 [1]. In order to obtain the most precise measurements, the integration period of the multimeter was selected to cover an integral number of cycles at the test frequency. The test frequencies were selected to optimize this process. For example, test frequencies of 0.06, 0.075, 0.08, 0.093 75, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, $\cdots$ Hz were integrated for 1000, 800, 750, 640, 600, 300, 200, 150, 120, 1000, $\cdots$ power line cycles, respectively. Measurements at the reference frequency (1 kHz for these tests) were interleaved between measurements at all other frequencies to compensate for drifts over the long measurement periods at low frequencies.

IV. Results

The measured low frequency ac–dc differences of the four multijunction converters ranged from 0.2% to 0.6%. However, the differences between simulated and measured values were as large as 0.07% [5]. So it was decided to use the more complex model described in [1] to improve performance. In this model, the peak-to peak variation $varpp(f)$ is centered at emf_{ref} on the measured transfer function curve (see Fig. 1). The average value of this curve $emf_{avg}(f)$ in the region defined by $Varpp(f)$ represents the better estimate of the output emf at frequency f. The ac–dc difference is given by

$$\delta(f) = (emf_{avg}(f) - emf_{ref})/emf_{ref}/n. \tag{2}$$

The simulated [using (2)] and measured ac–dc differences versus frequency for the four tested TVC's are shown in Figs. 2 and 3.

V. Conclusions

Simulations which model the low frequency response of thermal voltage converters based on easily measured parameters have been used to predict the low frequency ac–dc difference of four thin-film, multijunction TVC's. The models were verified by testing the TVC's using a digitally synthesized source which is assumed to be flat to within 0.001% in the range of 0.1 Hz to 100 Hz. The measured ac–dc differences of the measured converters ranged from 0.2% to 0.6% at 0.1 Hz. Using the simplest model, that scales the maximum low frequency ac–dc differences using the frequency response of the TVC, the differences between simulated and measured values were as large as 0.07%. The more complex model, that calculates the average value of a segment of the TVC transfer function, produced values closer to the measured values. Excluding a few outliers at very low frequencies, the simulate and measured values agree to within $\pm 0.01\%$. While it is possible to make more accurate measurements of ac–dc difference in 10 Hz to 1 kHz frequency range using reference TVC's with longer time constants, the model offers the advantage of predicting the ac–dc differences at any input voltage or frequency based on a set of measured TVC parameters.

Acknowledgment

The authors wish to thank M. Klonz from Physikalisch-Technische Bundesanstalt, and J. Kinard and T. Lipe from the Electricity Division at NIST for donating thin-film multijunction TVC's for this evaluation.

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